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*ASP Conference Series, Vol. **VOLUME**, **PUBLICATION YEAR***

****EDITORS****

Obscured Accretion and Black Holes

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Abstract. The evidence for obscured AGN and in particular for obscured quasars is discussed. The spectrum and source modelling of the X-ray Background suggests that most massive black holes grow by obscured accretion. A possible major growth phase which is Compton thick is explored and shown to be difficult to detect directly with current instruments.

1. Introduction

Obscured Active Galactic Nuclei (AGN) are required by most models for the origin of the 1–40 keV X-ray Background (XRB: Setti & Woltjer 1989; Madau et al 1994; Comastri et al 1995). Here I am interested in whether a) most massive black holes underwent an intrinsically-luminous, but obscured, phase and b), if so, was the absorption Compton-thick (i.e. column density $N_H > 1.5 \times 10^{24} \text{ cm}^{-2}$). In other words, did most massive black holes grow by obscured accretion?

I rely on the usual observational handles of the XRB, namely its spectrum, the extragalactic source counts, source identifications and, as a constraint, the infrared background.

As a hint that highly obscured AGN might be common, Matt et al (2000) point out that the 3 nearest AGN with X-ray luminosities above $10^{40} \text{ erg s}^{-1}$ (NGC4395, the Circinus galaxy and Cen A) are all highly absorbed, with the first two being Compton thick. The main issues here though are whether there are much more distant examples, and whether Compton-thick quasars exist.

2. Clues from the spectrum

The shape of the spectrum of the XRB is now well known from HEAO-1, ASCA and BeppoSAX, even if there remains some uncertainty about its normalization. In the 2–7 keV band it fits a power-law with photon index 1.4 (e.g. Gendreau et al 1995) and it peaks (in νI_ν) at about 30 keV (Marshall et al 1980). The flatness of the spectrum is only plausibly made by summing many absorbed sources. If these sources have typical intrinsic quasar spectra with a photon index $\Gamma = 2$ then most (> 85 per cent) of the accretion power must be absorbed (Fabian & Iwasawa 1999). Correction of the XRB spectrum for the minimum absorption necessary reveals the intrinsic mean energy density of radiation from accretion, which through $L = 0.1\dot{M}c^2$, yields the mean local mass density in black holes.

The result (Fabian & Iwasawa 1999) agrees with observations of that density, inferred from the motions of stars in galactic nuclei (Merritt & Ferrarese 2001).

To obtain the flat spectrum of the XRB all the way to its 30 keV peak requires that the sources dominating above about 10 keV are Compton thick. The major uncertainty in the translation from mean energy density to mean black holes mass is the ratio of the mean redshift to the radiative efficiency of accretion $(1+z)/\eta$. In the above $z \sim 2$ and $\eta \sim 0.1$.

3. Source identifications

In the medium hard band of 2–7 keV, the XRB has been resolved by Chandra (Mushotzky et al 2000; Barger et al 2001; Brandt et al 2001; Giacconi et al 2001) and XMM (Hasinger et al 2001). Bright source identifications in the harder 5–10 keV band have been done from BeppoSAX by the Hellas project (Comastri et al 2000).

Much has been said at the meeting about the faint sources found in deep exposures. Since however the 2–7 keV counts turn over around $10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1}$, source numbers are maximised per unit exposure time by using short, 10–20 ks exposures with Chandra and XMM. The sources thereby found are highly relevant to the XRB since more than half the background originates above that flux.

We (Fabian et al 2000; Crawford et al 2001a; Cowie et al 2001; Crawford et al 2001b) have been identifying serendipitous hard sources found in my Chandra cluster fields as a means to study this population. Some of the clusters, e.g. A2390, have been well-studied at other wavelengths, and with strong lensing enable us to go much deeper in all bands. Of particular note is that the A2390 field was the deepest exposure made with ISO.

The total exposure of the A2390 field is 19 ks and we have made 22 optical identifications (Crawford et al 2001b; Cowie et al 2001). Of 13 sources with spectroscopic redshifts most have soft X-ray spectra. These are Seyferts and quasars. A further 4 sources have photometric redshifts. Of the remaining sources 7 are hard and faint. The optical, X-ray and infrared spectra of two obscured quasars are shown in Figs. 1 and 2. Both are lensed by the cluster resulting in one being magnified by a factor of about 2 and the other by 8; both were detected by ISO (Lemonon et al 1999). The less magnified one (source A18) has an intrinsic 2–10 keV luminosity of about $3 \times 10^{45} \text{ erg s}^{-1}$ and $N_{\text{H}} \sim 3 \times 10^{23} \text{ cm}^{-2}$ (Fig. 1).

The $15 \mu\text{m}$ ISO flux shows that the absorbed X-rays and UV emission are reradiated in the mid-far infrared by warm dust (Fig. 2). The correlation of serendipitous X-ray sources with SIRTf images should be very fruitful.

Such work, together with the deep fields and other serendipitous sources studied by others, shows that obscured quasars exist. We have of course known for long that many powerful radio galaxies are obscured along our line of sight, and also, more recently, radio quasars (the red quasars; Francis et al 2000; BAL radio quasars; Najita et al 2000, Gregg et al 2001) and more generally BAL QSO (Gallagher et al 2001). In the unified model they appear as quasars when looked at closer to the jet direction. One example of a powerful distant radio galaxy is B2 0902 (Carilli et al 1994) at $z = 3.4$. Chandra finds this to

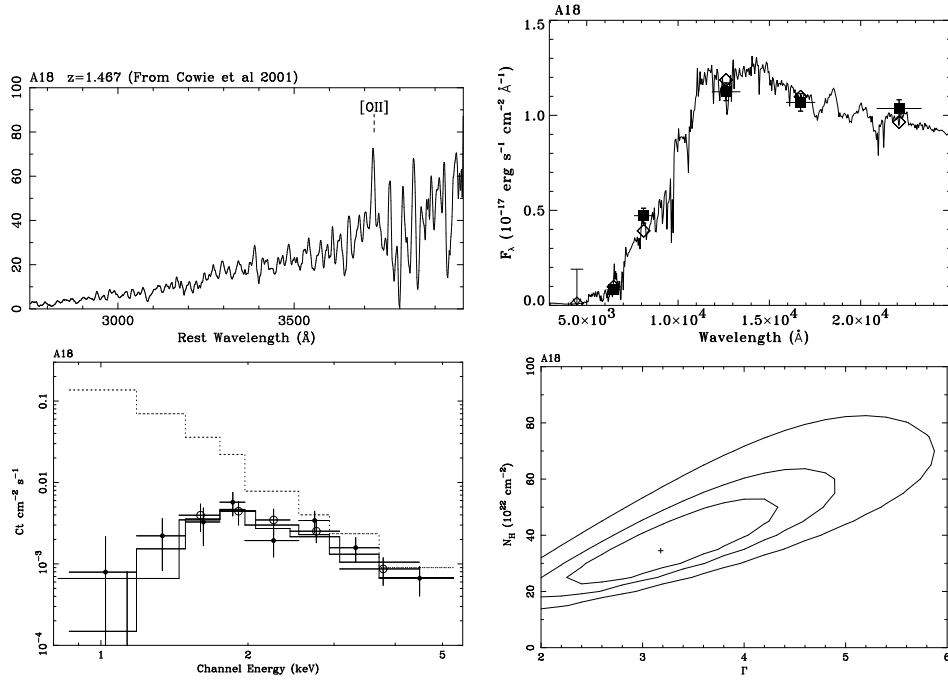


Figure 1. Spectral results for source A18 in the A 2390 field. Clock-wise from top left is shown the optical spectrum with [OII] emission (Cowie et al 2001), optical and near IR photometry with a HYPERZ galaxy fit, Contours of photon index Γ and intrinsic column density (the source is at $z = 1.467$), and finally the X-ray spectrum (the dashed line indicates what the spectrum would look like if the source had no intrinsic absorption). The last 3 panels are from Crawford et al (2001). The source is a powerful Type II quasar, with an intrinsic 2–10 keV luminosity of $3 \times 10^{45} \text{ erg s}^{-1}$.

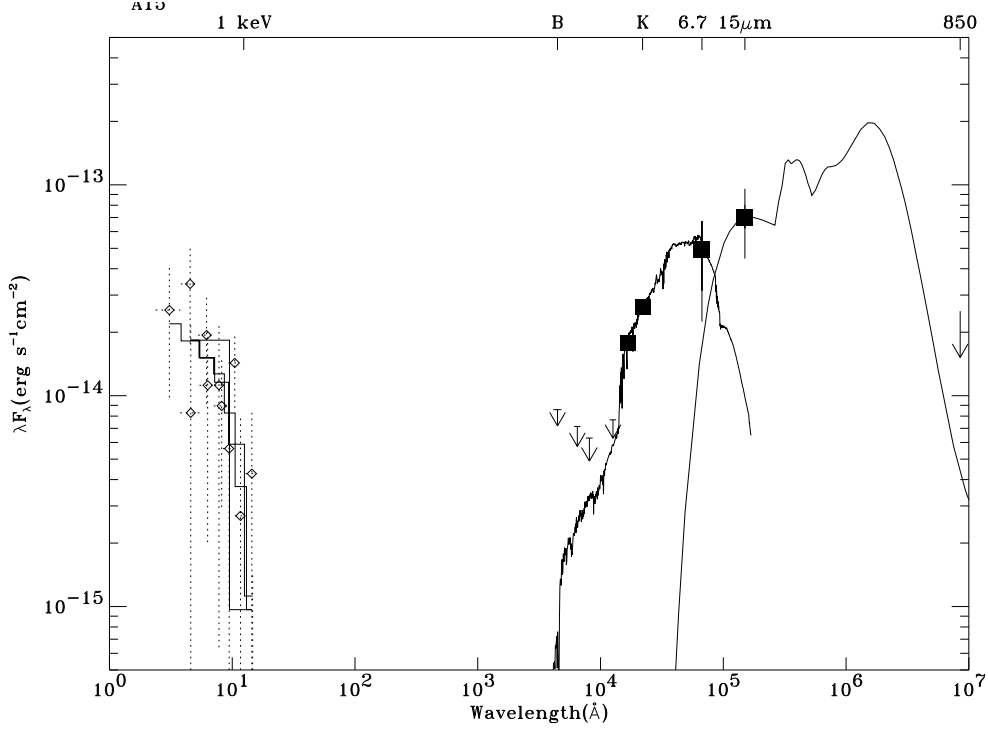


Figure 2. The spectral energy distribution of source A15 in the A 2390 field. The lensing magnification is about 8. Note the absorbed X-ray spectrum, the galaxy component (from a HYPERZ fit) between $10^4 - 10^5 \mu\text{m}$ and the warm dust component at longer wavelengths. The source has a photometric redshift of about 2.8 (Cowie et al 2001; Crawford et al 2001).

be highly absorbed, by a column of at least 10^{23} cm^{-2} and an intrinsic 2–7 keV power exceeding $10^{46} \text{ erg s}^{-1}$ (Fig. 3; Fabian et al, in preparation). Other highly absorbed objects are IRAS09104 (Franceschini et al 2000; Iwasawa et al 2001) and IRAS F15307 (Fabian et al 1996). Intrinsic absorption is also seen in several very distant blazars, at $z > 4$ (Boller et al 2000; Yuan et al 2000; Fabian et al 2001a,b).

4. XRB modelling

Models for synthesising the XRB can either work backwards in time using observed (often local) luminosity functions, or forwards in time using some evolutionary model for accreting black holes and their galaxy hosts. Examples of the first approach were presented by others at the meeting. Here I concentrate on the second approach, which may be preferable for the Compton-thick sources for which no luminosity function yet exists.

Wilman, Fabian & Nulsen (2000) have incorporated a simple obscured black hole growth model (Fabian 1999) into a semi-analytic model for galaxy forma-

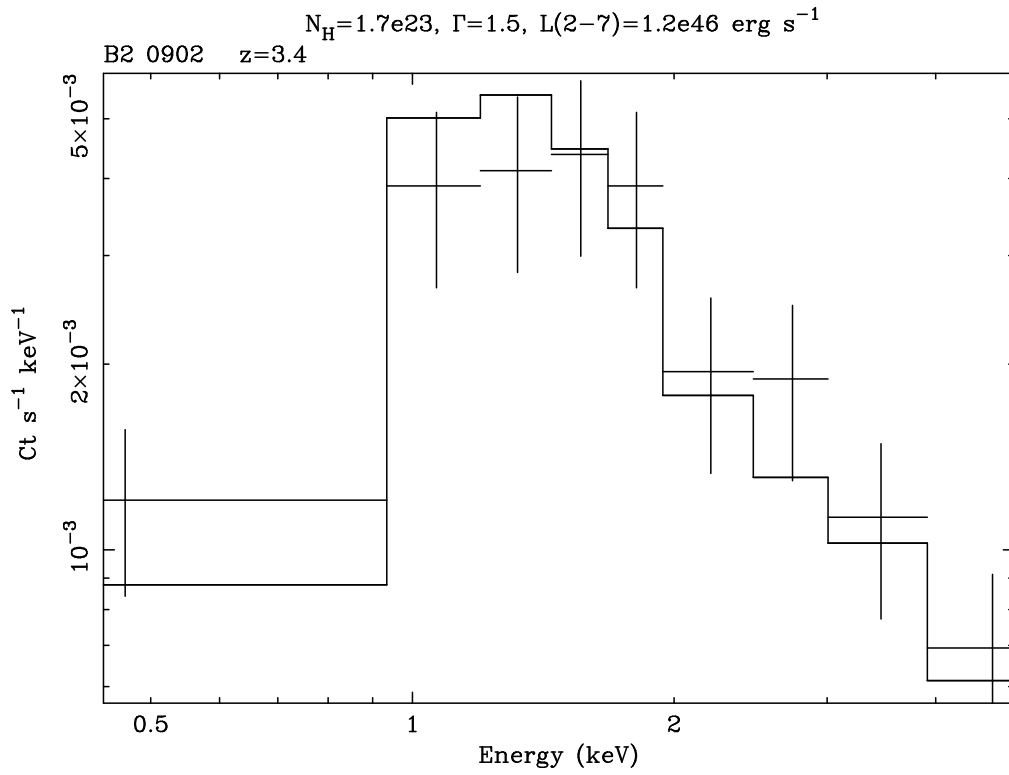


Figure 3. The Chandra X-ray spectrum of the $z = 3.4$ radio galaxy B2 0902 (from Fabian et al, in prep). Note the high power and large absorption..

tion (Nulsen & Fabian 1999). Basically the (isothermal) galaxy has a significant fraction of its mass in cold, obscuring gas. A central black hole grows by accretion until its wind has enough thrust to eject that gas. Force balance leads to the black hole mass at this stage being proportional to the velocity dispersion of the galaxy to the fourth power (an earlier model by Silk & Rees 1998 uses an energy argument to obtain the fifth power). The gas in the galaxy is just Thomson thick when ejection takes place. Afterwards the quasar is unobscured and lasts as long as there is any mass in its disc. The major growth phase for massive black holes is then before the normal unobscured phase and thus before $z \sim 1.5$. Some action still continues after that time from late forming haloes and also if the black holes are revived by mergers.

The model results are in reasonable agreement with the observed XRB spectrum and source counts. This does not of course prove that it is the right answer, and is more a demonstration that such forward modelling is possible and can yield agreement.

5. Distant Compton-thick sources

The above model predicts that much of the peak of the XRB between 10–30 keV is due to Compton-thick quasars. It also predicts the numbers of such sources which are detectable. The numbers for Chandra and XMM are rather disappointing, being only a handful per deep exposure (Fabian et al 2001) and most are within a factor of 1.5 of the detection threshold. Despite the negative K-correction for absorbed X-ray sources (Wilman & Fabian 2000), few sources distant enough to redshift their emission to a few keV are bright enough to be detectable.

The net result is that Compton-thick sources are going to be difficult to find directly, even with powerful instruments such as Chandra and XMM. They may appear indirectly by scattered emission (e.g. Norman et al 2001) but their true nature will be difficult to discern.

Resolving the brighter members of the distant, Compton-thick class may be best done with harder X-ray instruments such as on Astro-E-2, Constellation-X and Xeus, as well as surveys by LOBSTER and especially EXIST (Grindlay et al 1999). When this happens, there will again, justifiably, be the statement that the ‘XRB has at last been resolved’.

Much of the power in the XRB is at 10–40 keV. It is difficult to make the 30 keV peak itself with synthesis models using very distant obscured AGN, due to the effect of redshift. Enhanced metallicity in the absorbing gas can somewhat stave off the effects of Compton down-scattering in the absorber (Willman & Fabian 2000), but probably the high energy of the peak is due to a significant contribution by the lowest redshift Compton-thick Seyferts. If so, the 5–20 keV band probes the highest redshifts. And the 20–50 keV sky will be rich in new lower-redshift sources.

6. Acknowledgements

I thank Richard Wilman, Carolin Crawford and Poshak Gandhi for discussions, Robert Schmidt for technical help, and the Royal Society for support.

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